Hydrology, water quality, and restoration potential for the Upper Big Darby Creek, Central Ohio

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Abstract

The restoration of riparian buffers as well as the creation and restoration of wetlands along streams are practices that can be used to control point and non-point source pollution. Our study provides hydrology and water quality data from 2000-02 in anticipation of recommending restoration of the headwaters of the Big Darby Creek Watershed in central Ohio. One tributary of concern in the headwaters, Flat Branch, contributed 11% of the total river flow during April 2002 flooding and 56 and 88 % of the flow in the headwater study area during nongrowing season (winter and early spring) and growing season (summer and early fall) respectively. There were significant differences in water chemistry, both temporally and spatially, at each sampling station within the upper watershed. Flat Branch was seasonally or continuously higher in temperature, pH. and turbidity, and lower in dissolved ions and oxygen than Darby Creek itself. Low dissolved oxygen measured at dawn during the summer months and caused by diurnal metabolism in the water column is also a concern in Darby Creek. We propose the creation/restoration of riparian wetlands at the confluence of the Big Darby and Flat Branch as one solution to degrading water quality in the upper Big Darby watershed. Flood pulses, particularly from the Flat Branch, could be directed to riparian wetlands, which would minimize downstream erosion and capture the water exactly when several pollutants (sediments, nitrates, etc.) are in higher concentrations. The restoration area could have flood control, habitat, and ecotourism values as well.

Introduction

Riparian forests and wetlands enhance stream ecosystems and their water quality (Odum 1981, Naiman and Decamp 1997, Ward 1998, Mitsch and Gosselink 2000, Sweeney and others 2002, Mitsch and Jørgensen 2004). Restoration of riparian buffers and wetlands along streams stabilize stream channel morphology in addition to controlling non-point source pollution coming from the landscape. They also provide refugia for a great variety of wildlife and some fish species associated with the streams and rivers. If overbank flooding occurs from the stream and river into the riparian forests and wetlands, sediments can be deposited on the floodplain from the river while particulate organic matter can be exported to support detrital food chains in the stream.

A number of research projects around world have shown how the functions gained from riparian restoration can benefit both nature and humans (Kadlec and Hey 1994, Jacks and others 1994, Moustafa 1999, Nairn and Mitsch 2000, Spieles and Mitsch 2000, Hoagland and others 2001, Mitsch and others 2001, 2002, Henry and others 2002). Peterjohn and Correll (1984) and Lowrance and others (1984) demonstrated that riparian forests of coastal plain agricultural watersheds can be nutrient sinks that buffer the nutrient discharge from surrounding agroecosystems. They also showed that nutrient uptake and removal by soil and vegetation in the riparian ecosystem prevented agricultural upland outputs from reaching stream channels. Most recently, Mitsch and Jørgensen (2004) concluded from a review of many studies that, because chemical and biological conditions will respond accordingly, if the proper hydrologic conditions are developed, then riparian restoration can lead to both short- and long-term water quality benefits. However, there are still very few techniques to assess the viability of riparian restoration to an entire watershed. Successful stream restoration depends not only on understanding the physical and biological processes that influence ecosystems at the watershed scale, but also in the proximity of the restoration effort to the sources of disturbance (Goodwin and others 1997, Tein and others 1999, Ward and others 1999, Poudevigne and others 2002, Mitsch and Jørgensen 2004).

Our study investigates the potential of restoring the headwaters of the Big Darby Creek Watershed in central Ohio. Big Darby Creek is a stream of relatively high water quality and biological diversity, but recent upstream developments (industrial and agricultural) have raised concerns about pollution effects downstream. Properties adjacent to the creek in the upstream reaches were purchased by the Ohio Chapter of The Nature Conservancy in the 1990s and early 2000s, leading to discussions on the restoration of stream channels, wetlands, and/or riparian ecosystems in this watershed to improve water quality, ameliorate flood peaks, provide habitat, and improve/maintain the biological character of the creek. Any such project would need both pre- and post-restoration monitoring to determine the effectiveness of the restoration. The creation of any wetland/riparian system would require complete data on stream hydrology for example. Because the ability of wetlands to trap or transform nutrients generally increases as the water retention time increases, our study here emphasizes understanding the hydrology and water chemistry dynamics temporally and spatially within the upper watershed network. The main goal of this study is to assess the quality of the streams in the vicinity of the potential restoration sites and to provide assistance on the siting and design of riparian restoration in the study area.

Methods

Study site

Our study watershed, with an area of 127 km^2, is the headwaters of Big Darby Creek in Logan, Union, and Champaign counties in central Ohio (Figure 1). Big Darby Creek eventually flows into the Scioto River, a major tributary of the Ohio River. The geology of the Big Darby Creek watershed was defined during the glacial advances and retreats of the Wisconsin glaciation dating back 15,500 to 17,00 years before present. The upper most bedrock units are Silurian-Devonian limestone and dolomite. The average slope of the upper Big Darby is 6.5%, where the terrain is flat to gently rolling with more than 90% of the land having slopes less than 6%. Soils are silty clay loams with moderately slow to slow subsoil permeability and low to moderate erosion hazards (U.S. Environmental Protection Agency 1996, Yu and Schwartz 1999). Prior to European/American settlement, the Big Darby Creek watershed consisted primarily of wet prairies in the flat and upland regions and mixed oak forests and savannahs on its gently sloping knolls (The Nature Conservancy Ohio 1999). Wetlands made up a significant part of the original Upper Big Darby watershed. Bear Swamp, also known as Flat Woods, was a large, well-developed wetland in the headwaters of the Big Darby (Ohio Historical Society 2001).

The first permanent settlers came to Union County in 1798 (Ohio Historical Society 2001). Since then, the Big Darby Creek watershed has been drained, and today more than 90% of its wetlands have been converted to agricultural fields and other development (The Nature Conservancy Ohio 1999). Presently, the upper watershed of the Big Darby is a productive agricultural area with a diverse range of land uses including corn-soybean crop rotation, livestock pasturing, forest and woodlot management, and urban/residential use (The Nature Conservancy Ohio 1999). Significant industrial development occurred in the Upper Big Darby Creek watershed in the 1970s and 1980s with the establishment of an industrial park for manufacturing Honda motorcycles and automobiles. Currently, that activity takes up about 24 % of the Upper Big Darby watershed, with much of the drainage from that development concentrated in a stream known locally as Flat Branch (see Station 3 on Figure 1).

Aquatic surveys of the Upper Big Darby watershed taken

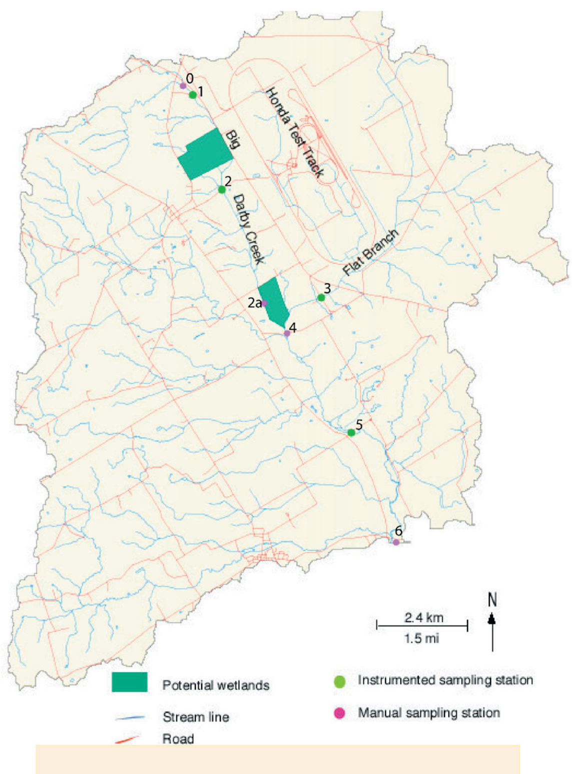

Figure 1. The Upper Big Darby Creek watershed study area, showing sampling stations and potential locations wetland creation/restoration as determined by The Nature Conservancy available real estate.

by the Ohio EPA prior to our study show a general increase in the number of invertebrate taxa sampled per unit effort from the low order headwaters of the Big Darby to the end of the study reach (Table 1). But there are some signs of invertebrate diversity impact below the confluence of Big Darby with Flat Branch. A maximum of 86 taxa occur in the Big Darby north of the confluence with Flat Branch; this decreases to 73 taxa downstream of Flat Branch. The Invertebrate Community Index (Ohio Environmental Protection Agency 1989) and Qualitative EPT richness index (the sum of the number of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) taxa present) are high both upstream and downstream of the Flat Branch. Fish count data were provided from the Ohio EPA for a 3.9-km stretch of the Upper Big Darby only upstream of its confluence with the Flat Branch for 1997, 1999, and 2000 (Table 2). The number of species present changed both from year to year and from upstream to downstream, but was always highest near our Station 2a, immediately upstream of the Big Darby confluence with Flat Branch. No fish data were available for Flat Branch or downstream of Flat Branch.

Field sampling

Stream stage gage stations with Ott Thalimedes data loggers were installed at 4 locations (Stations 1, 2, 3 and 5 in Figure 1) in the Upper Big Darby watershed. Streamflow was calibrated to stage with the assistance of the U.S. Geological Survey (USGS) for Flat Branch Creek (Station 3) and Big Darby Creek (Station 5). The resulting rating curves (relation between stage and discharge) were fit to polynomial relationships (Table 3) and significant correlation relationships (R^2>0.999) between observed and simulated discharge were observed for Stations 3 and 5. Annual mean historical streamflow data at the downstream end of the Big Darby Creek Basin during the period of 1922 to 2001 were obtained from USGS hydrological station 3230500. Precipitation data were made available from Honda Inc. at their facility in the watershed.

Table 1. Macroinvertebrate distribution in the Upper Big Darby Creek during 1997. Data provided by Ohio EPA

Closest Station*	0	1	2	2a	6
River Mile	83.2	82.5	81.5	79.3	69.4
No Quantitative Taxa	39	33	39	62	42
No Qualitative Taxa	44	33	38	54	59
Total Taxa	70	54	58	86	73
No Organisms	1378	1130	1558	1558	1600
ICI	48	40	38	52	54
Qual EPT	16	7	5	16	22

ICI = Ohio EPA Invertebrate Community Index
Qual EPT = Sum number of taxa of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)
* see Figure 1

Table 2. Size and distribution of fish in the Upper Big Darby in 1997, 1999 and 2000. Sample stations are sites chosen by Ohio EPA.

2000 Closest Station*		1	2	2a
River Mile		82.6	81.5	80.8
Total Fish		1666	815	364
Relative Number		2499	1287	575
Relative Weight		6.34	1.2	7.93
No Species		12	12	13
1999 Closest Site	0	1	2	2a
River Mile	83.2	82.6	81.5	80.8
Total Fish	714	2556	809	1523
Relative No	1428	2270	1213	1216
Relative Weight		3.57	3.39	14.22
No Species	14	17	16	21
1997 Closest Site	0	1	2	2a
River Mile	83.2	82.6	81.5	80.8
Total Fish	1144	1553	1985	1210
Relative No	1072	1456	1861	682
Relative Weight	5.22	2.94	8.48	9.18
No Species	11	13	18	21

* see Figure 1

We manually monitored temperature, dissolved oxygen, conductivity, pH, and reduction potential at 4 instrumented sampling stations and at 3 manual sampling stations on a weekly basis with a YSI 610XL sonde. Manual grab samples were also taken weekly for nutrient analyses. A YSI 610XL water quality sonde was installed at station 5 late in our study to investigate stream temperature, dissolved oxygen, conductivity, and pH at 30-min intervals for one month in summer 2002.

Lab analysis

Manual water samples were taken to the laboratory and preserved according to standard methods (USEPA 1983, APHA 1996). They were analyzed for soluble reactive phosphorus, total phosphorus, and nitrate-nitrogen using a Lachat QuickChem FIA+ 2000 series in Ohio State University Ecosystem Analytical Laboratory. Samples taken from the auto samplers were used to estimate water quality during flooding events. These samples were measured for

Table 3. Relationship between streamflow (Q) and staff gage readings (X) for Flat Branch (Stations 3) and Upper Big Darby Creek (Station 5) as shown in Figure 1.

Station ID	Parameters				
	a	b	c	d	R^2
Flat Branch					
$0.11<X\leq0.36$	2.099	7.502	9.067	3.684	0.9999
$0.36<X<1.22$	2.924	14.013	30.690	29.857	0.9992
$1.22\leq X<1.92$	0.677	61.376	-294.187	860.749	0.9990
Darby Creek down stream of Flat Branch	1.118	1.387	-0.802	-0.312	0.9998

the following: conductivity, nitrate, and turbidity. Monthly samples were analyzed at the STAR laboratory at Ohio State campus in Wooster for major and trace elemental analysis by ICP emission spectrometry.

Land use analysis

We developed a data storage system with ArcView 3.2 (ESRI 2000) that displays prominent land-use features and other aspects of the watershed that contribute to the water quality of Big Darby Creek.

Results and Discussion

Hydrologic Influence of Flat Branch on the Upper Big Darby Watershed

Three of the five wettest years from the period 1922 to 2001 have occurred since 1990 in the Darby Creek watershed, while there has been no dry year since 1987 (Figure 2). For the Upper Big Darby Creek, April 2002 was the wettest month during our study period of 2000 - 2002 (Figure 3). The Flat Branch contributed a significant part of the flow to Big Darby Creek. When compared to flow downstream at Station 5 on the Big Darby, Flat Branch Creek contributed 56% of the Big Darby Creek flow during flood periods and 88% of the flow during normal flow periods (Table 4). When comparing the contribution of flooding events to the downstream USGS station on Big Darby Creek at Darbyville well below our Upper Big Darby study area, our study showed that Flat Branch contributed 11% of the total river flow during April 2002 flooding. Flat Branch contributes more flow to the overall Darby Creek ecosystem than had been suspected by us or other investigators. This is significant because hydrological dynamics is a driving force in river/stream ecosystems (Allen 1995, Poff 1997, Richter 1998). Streamflow controls nutrient and chemical loading rates, affects the exchanges of organisms and energy patterns in time and space, and also affects physical attributes such as channel morphology (Whitton 1975, Allen 1995, Ward and Stanford 1995, Richter 1998, Mitsch and Jørgensen 2004). Thus, the high contribution of flow to the Big Darby Creek from the Flat Branch has significant implications on the ecosystem health in Big Darby Creek itself.

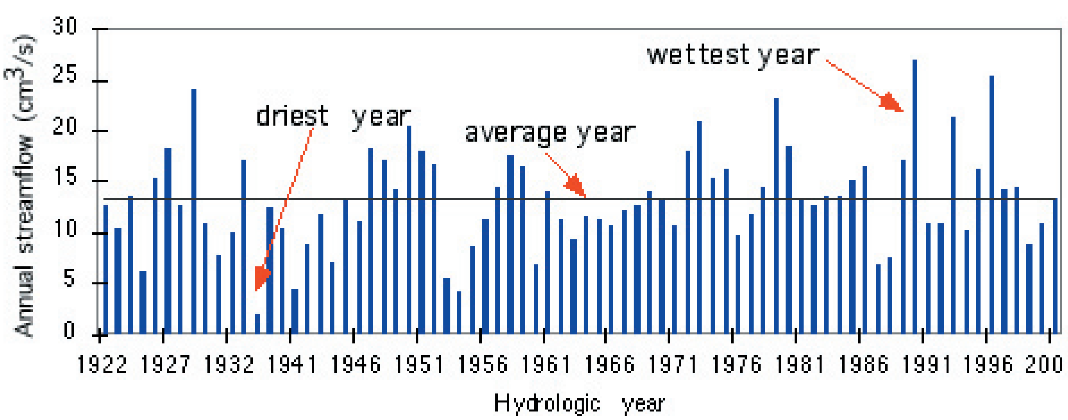

Figure 2. Annual streamflow of Big Darby Creek from 1922 to 2002 (USGS station 3230500, Darbyville, OH).

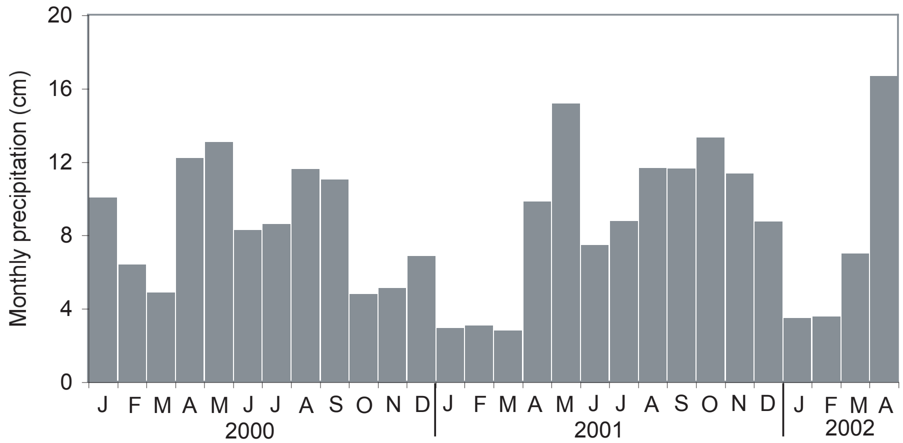

Figure 3. Precipitation data from Union County (Honda Inc. weather station), January 2000- April 2002.

Flat Branch Water Quality

Conductivity is higher in the growing season than in the wetter non-growing season in the Big Darby upstream of its confluence with Flat Branch and drops about 100 μmhos/cm (20%) downstream of Flat Branch, illustrating the distinct difference in water sources of the two streams when they meet (Figure 4). Flat Branch is much more dominated by low-ionic surface flow resulting from runoff than by groundwater flow that heavily influences the upper reaches of the Big Darby. The Upper Big Darby is significantly higher in turbidity after it passes the confluence with the Flat Branch (Figure 4). Turbidity in the Big Darby Creek doubles from 20 to 40 NTU in the growing season and more than doubles from 5 to 12 NTU in the non-growing season below the confluence. Phosphorus increases significantly between Stations 2 and 2a in Darby Creek. We believe this effect is due to a small Logan County treatment plant which discharges into the Big Darby Creek upstream of its confluence with Flat Branch. Nitrate-nitrogen does not increase in Big Darby Creek due to Flat Branch and concentrations are, not unexpectedly, quite variable especially in the non-growing season (error bar is 3 mg-N/L) compared to the growing season (error bar is generally less than 1 mg-N/L). Significant differences of nitrate-nitrogen concentrations were detected during a winter flooding event in 2001 when auto-sampling showed a doubling in nitrate-nitrogen from about 0.8 mg-N/L to about 1.6 mg-N/L in one hour during the flood event.

Table 4. Streamflow (average ± std. error (# of events)) of Flat Branch (Station 3) as a percent of Darby Creek streamflow at Station 5, March 9 - August 22, 2002

	Flat Branch (Station 3)	Darby Creek (Station 5)
Flood Conditions		
mean (m^3/s)	14.6±0.7 (2)	26.2±0.9 (2)
ratio		0.56
Low Flow		
mean (m^3/s)	0.7±1.0 (22)	0.8±0.9(19)
ratio		0.88

We statistically compared Station 2 water quality (Darby Creek upstream of Flat Branch) and Station 5 water quality (downstream of Flat Branch) with Flat Branch (Table 5). There were significant differences in turbidity during the growing (non-flooding) and non-growing (flooding) seasons and significant differences in dissolved oxygen and conductivity during the growing season between Flat Branch and both Darby Creek stations. Water from Flat Branch is more turbid, lower in dissolved ions, and lower in dissolved oxygen than is water in Darby Creek in lower flow conditions of the summer and fall. During these low-flow conditions, Flat Branch is also statistically warmer and has higher pH compared to the upstream station 2. No statistical differences were seen between the Big Darby and Flat Branch for the three nutrient parameters analyzed.

Significant diurnal changes occur in temperature dissolved oxygen, pH, and conductivity in the summer in Upper Big Darby Creek at Station 5 (Figure 5). These patterns are driven by aquatic metabolism (primary productivity and respiration) in the water column that is particularly significant during low-flow summer conditions. This photosynthesis and respiration, in turn, is caused by high nutrients in the water column. When storm pulses (floods)

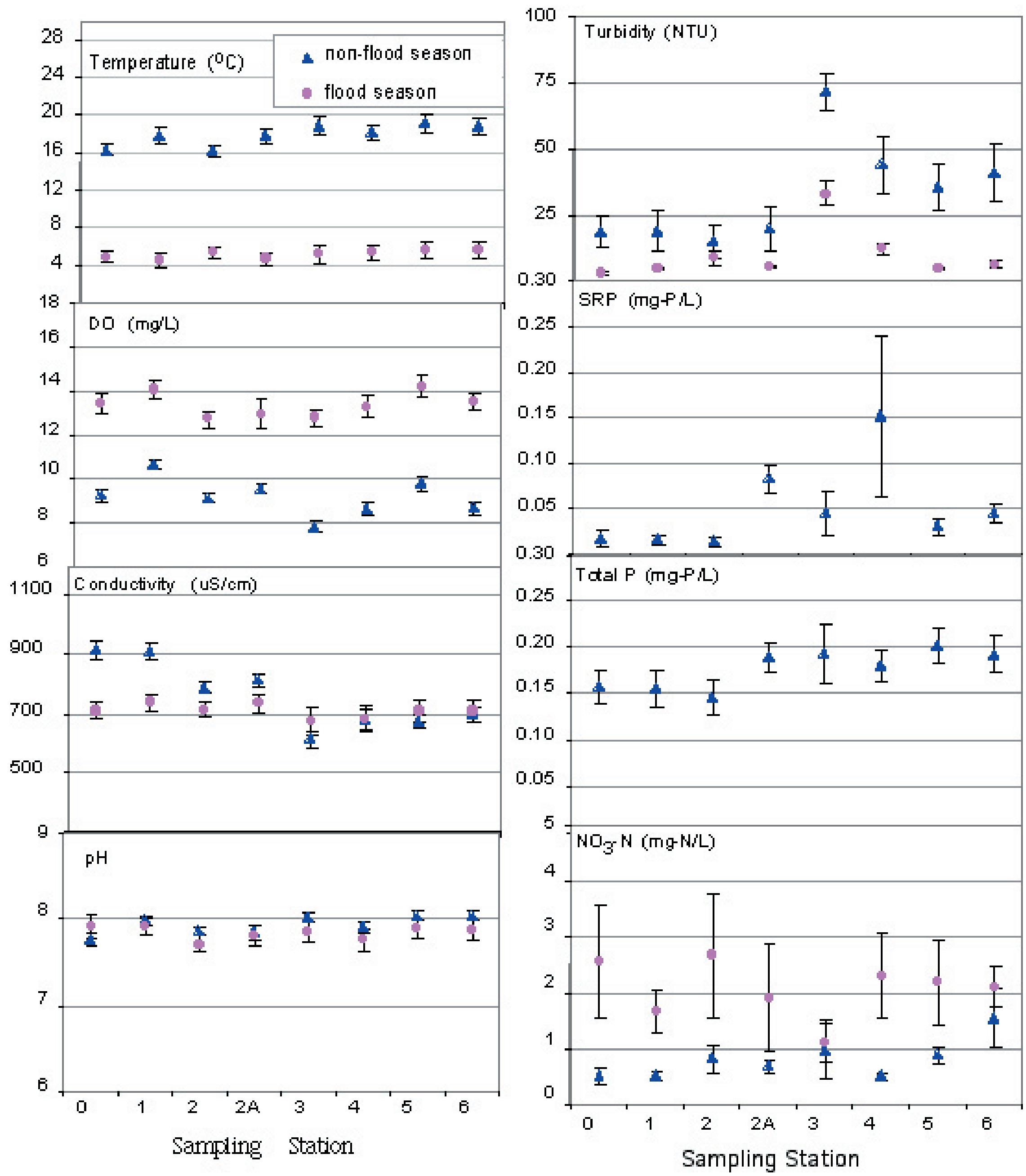

Figure 4. Water quality parameters for each monitoring site in Upper Big Darby Creek during the study period. Data are divided into non growing (flood season) and growing season (non-flood season).

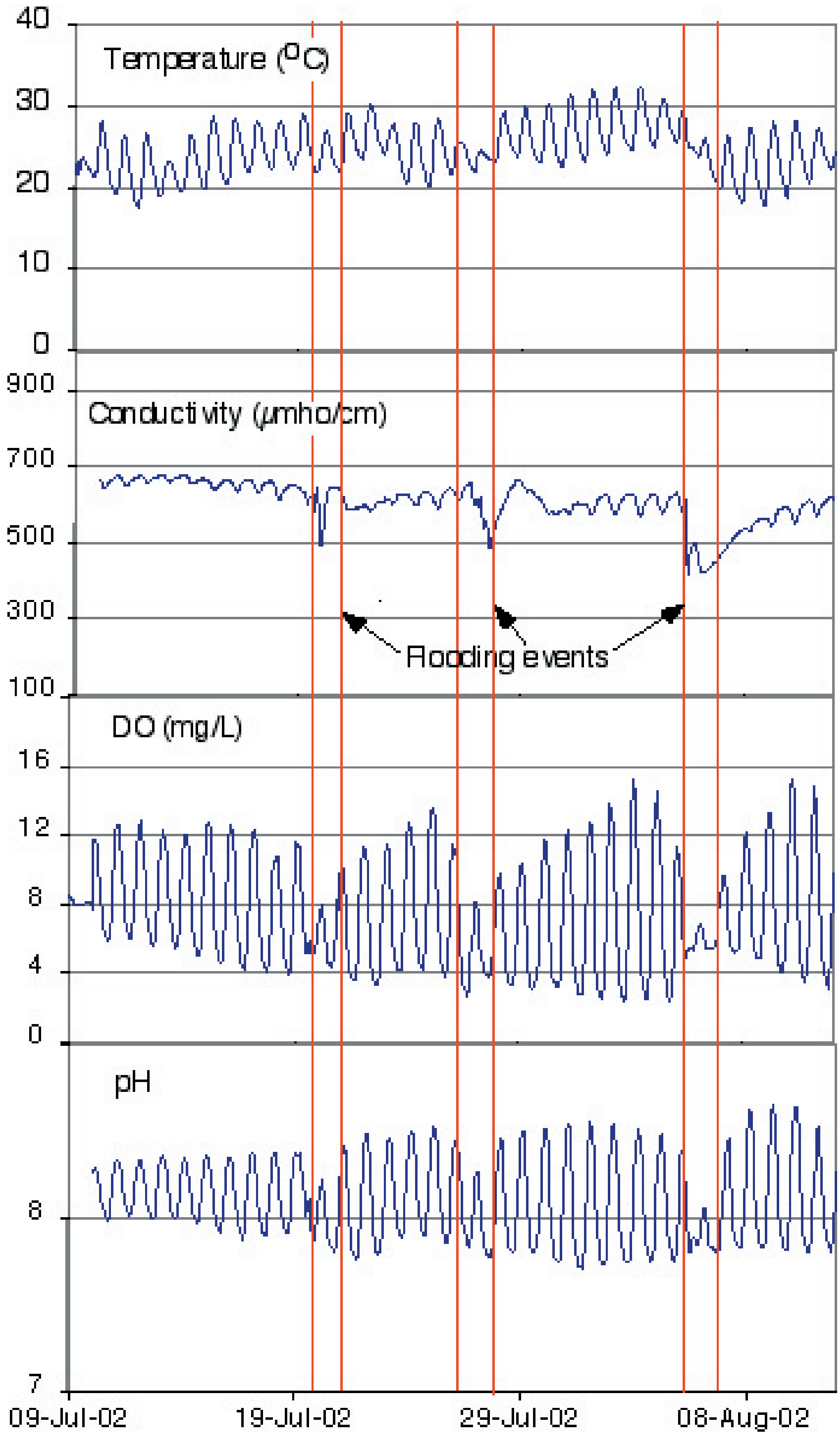

Figure 5. Continuous water quality data at Station 5, Big Darby Creek, July 9 – August 13, 2002.

occur, as on July 20, July 27, and August 6, diurnal patterns are dampened (Figure 5). After these pulses, the diurnal patterns reestablish themselves in a few days. These high-frequency data also illustrate that dissolved oxygen in the Big Darby dropped to almost 3 mg/L at dawn on several days in late July and early August, levels that are threatening to aquatic ecosystem health. Sampling the river manually would never have revealed these potentially threatening low levels. Flood pulses, when they occur, temporarily remove the low dawn dissolved oxygen conditions until aquatic metabolism increases to the point where dissolved oxygen at dawn decreases below 3-4 mg/L again.

Specific dissolved ions and trace metals showed some differences between Flat Branch (Station 3) and three other Darby Creek stations (Tables 6 and 7). Flat Branch had higher concentration of two significant metals (Al and Fe) than any of the three other sampling stations on the Darby. Aluminum, a chemical that can threaten aquatic communities at concentrations seen in the Flat Branch, remains high in the Darby downstream of Flat Branch (93 μg/L downstream vs. 39 μg/L upstream). Chronic effects on fish growth at Al concentrations as low as 100 μg/L have been detected in the poorly buffered lakes affected by acid deposition in the Adirondacks of northeastern USA (Cronan and Schofield 1979). Flat Branch also was significantly higher in arsenic (As) than Station 2 in Darby Creek. Arsenic average concentrations at all Darby Creek and Flat Branch stations (average= 44 μg/L at Station 1; 75 μg/L at Station 5) are above the USEPA (1980, 1981) 24-hr maximum criteria recommended for the protection of freshwater aquatic life of 40 μg/L. But the As averages in Table 6 should be viewed with some caution; the level of detection was 50 μg/L for As so our protocol then used 25 μg/L of all such numbers below the level of detection for calculating averages. Conversely, Flat Branch had lower concentrations of sulfur and barium than did two and three Darby Creek stations respectively and, as would be expected from conductivity data described above, lower concentrations of the major dissolved ions calcium and magnesium that most of the Darby Creek sampling stations (Table 7). The high concentrations of aluminum and arsenic in Flat Branch give some concern for that stream contributing to the degradation of aquatic communities in Big Darby Creek downstream of Flat Branch.

Restoring Upper Big Darby Creek

Big Darby Creek is a stream of great importance in Ohio because of its status as an Ohio Scenic River. Its aquatic life

Table 5. Paired sample comparison of water quality at stations 2 and 5 with water quality at station 3 (Flat Branch) for growing season (non-flooding period) and non-growing season (flooding period). Statistics is T-test (95% Confidence Interval of the Difference).

Parameter	Paired T-Test, p-value Station 2	 Station 5
1. Growing season (fewer floods)		
Temperature	0.000	nd
DO	0.000	0.000
pH	0.000	nd
Conductivity	0.000	0.003
Turbidity	0.000	0.000
Soluble Reactive P	nd	nd
Total P	nd	nd
NO3+NO2	nd	nd
2. Non-growing season (period of floods)		
Temperature	nd	nd
DO	nd	0.004
pH	nd	nd
Conductivity	nd	nd
Turbidity	0.003	0.001
Soluble Reactive P	-	-
Total P -	-	
NO3+NO2	nd	nd

nd= no significant difference at α = 0.05

Table 6. Selected major ions and metals from normal flow and one storm event during the period June 2001 - June 2002 for Upper Big Darby Creek. Station numbers are located on Figure 1. Data in bold for Station 3 (Flat Branch) indicate where that tributary is statistically different than at least one of the other Darby Creek stations (see Table 7).

	Station 1				Station 2				Station 3				Station 5			
	Mean	Max	Min	Storm	Mean	Max	Min	Storm	Mean	Max	Min	Storm	Mean	Max	Min	Storm
Major Elements, mg/L																
Ca	77±0.0	100	43	43	70±0.0	91	41	41	**44±0.0**	**72**	**24**	**24**	60±0.0	84	32	32
K	2±3.0	6	1	6	3±2.4	6	1	6	16±1.7	39	5	7	8±3.3	25	3	8
Mg	36±0.0	44	17	17	31±0.0	42	15	17	**15±0.0**	**25**	**7**	**7**	25±0.0	37	10	10
Na	14±0.0	43	5	5	15±3.4	46	7	5	33±8.5	100	5	5	18±5.8	52	5	5
S	25±4.3	62	8	8	21±2.0	32	11	8	**17±2.3**	**29**	**6**	**6**	16±2.2	26	7	7
Si	2.3±0.3	4	1	3	2.6±0.2	3	1	3	**1.7±0.3**	**3**	**0**	**3**	2.1±0.3	3	0	3
Fe	0.1±0.0	0	<0.01	0.4	0.1±0.0	0	<0.01	0.40	1±0.1	1	<0.01	0.5	0.1±0.1	0	<0.01	0.4
Other elements, μg/L																
Ag	19±4.54	50	<5	25	19±5	50	<5	25	25±5	50	<5	25	20±6	50	<5	<5
Al	41±21	251	<40	251	39±16	191	<40	46	**152±51**	**473**	**<40**	**473**	93±33	300	<40	300
As	44±12	127	<50	62	50±14	138	<50	23	**60±20**	**183**	**<50**	**23**	75±26	201	<50	23
B	36±7	62	<10	62	29±4	46	<10	46	31±3	45	<10	33	29±4	43	<10	40
Ba	51±4	76	26	45	52±5	80	29	36	**39±6**	**75**	**22**	**24**	52±6	82	30	34
Be	2±1	7	<2	7	1±0	<2	<2	<2	1±0	<2	<2	<2	1±0	<2	<2	<2
Cd	2±1	10	<2	10	1±0	2	<2	<2	2±0	2	<2	2	2±0	3	<2	<2
Co	6±1	15	<10	15	5±0	<10	<10	<10	5±0	<10	<10	<10	5±0	<10	<10	<10
Cr	3±1	12	<5	12	3±0	<5	<5	<5	3±0	<5	<5	<5	3±0	<5	<5	<5
Cu	6±1	13	<10	13	6±1	5	<10	5	5±0	<10	<10	<10	6±1	10	<10	10
Mn	2±1	10	<2	10	2±0	5	<2	2	4±2	26	<2	6	1±0	3	<2	3
Mo	7±1	18	<10	18	5±0	<10	<10	<10	8±2	19	<10	<10	7±1	13	<10	<10
Ni	5±0	<10	<10	<10	5±0	<10	<10	<10	5±0	<10	<10	<10	5±0	<10	<10	<10
Pb	10±0	<20	<20	<20	10±0	<20	<20	<20	10±0	<20	<20	<20	13±3	<20	<20	<20
Se	67±12	173	<100	109	56±6	114	<100	50	63±9	128	<100	50	57±7	109	<100	109
V	5±2	10	<10	<10	7±5	22	<10	<10	5±0	<10	<10	<10	7±4	15	<10	<10
Zn	8±2.31	22	<5	13	11±6	72	<5	9	11±4	50	<5	18	7±2	13	<5	8

Number of samples = 11 (St 1, 2, and 3) and 8 (St. 5).

when a reading is reported as being below the level of detection, detection level/2 was used as estimate for determining averages is threatened by a combination of altered hydrology and a deterioration of water quality that includes high turbidity, nutrients, and some trace metals. The high nutrients, in turn, cause high diurnal patterns of dissolved oxygen in the Darby, a condition that also threatens aquatic life when dawn dissolved oxygen goes below 5 mg/L. Increased low-ion surface runoff in the Flat Branch, compared to groundwater flow which dominates much of the rest of the Upper Darby, is an indicator that Flat Branch water is polluted from a combination of nonpoint sources including parking lot and industrial runoff and drained agriculture land. Increased flow, particularly during flood events, has caused tributaries and the creek itself to change its erosion-sedimentation patterns, also increasing turbidity.

The sources of the pollutants to the Upper Big Darby are many and come from agriculture, highway runoff, and industries. They are mostly non-point pollution sources that are difficult to regulate or control. It would be difficult to identify specific sources of nutrient, sediment, and trace element pollution in the Upper Big Darby or to control specific pollution sources beyond what is being done now. Based on the data presented in this paper and on the interest for some restoration in the Upper Big Darby by The Nature Conservancy and other agencies and NGOs, we believe that creation of a riparian wetland system, if properly located near the confluence of the Upper Big Darby and the Flat Branch, could contribute significantly to water quality improvement in the Upper Big Darby.

Restoring and creating wetlands could enhance water quality, flooding control, and ecosystem function in the Upper Big Darby Creek. The importance of such long-term restoration has been emphasized by Richardson and Vaithiyanathan (1995), Whigham and others (1995), Costanza and others (1997), Mitsch and Gosselink (2000), Mitsch and others (2001), and Poudevigne and others (2002). Storm events are often the main mechanism for transporting pollutants, causing biological degradation downstream, but because of the logistics of manual sampling, these measurements are often not taken. In the Upper Big Darby, NO_3, Al, Fe, P, and Si increased with storm flows. The flood pulsing and water quality coming from the Flat Branch tributary of the Big Darby is of particular concern. This tributary is turbid and has higher concentrations of several pollutants than do the upstream reaches of Big Darby Creek. Controlling pollution in the Flat Branch is particularly significant as it contributes 56 % of the flow of the Big Darby Creek during flood events and 88 % of the flow during normal flow.

Most of the pollutants seen in this study can be controlled through riparian restoration projects. If the river is permitted to flood its riparian zone with greater frequency, then the effects of sediment and nutrient pollutants downstream, particularly during storm events, could be minimized. Creation and restoration of wetlands will also provide important ecological functions within the headwater watershed. Vegetation is productive and a portion is exported during seasonal flood pulses; exported organic carbon is an important food resource for aquatic communities (Dosskey and Bertsch 1994).

We propose an investigation into the creation/restoration of riparian bottomlands at the confluence of the Big Darby and Flat Branch as one solution to the problem (Figure 6). Flood pulses, particularly from the Flat Branch, could be directed to riparian wetlands, capturing the flood pulse, thus minimizing downstream erosion as well as pollutant transport and capturing the water exactly when several chemicals (sediments, nitrates, etc.) are in higher concentrations. The value of such an effort would be three-fold:

1) water quality of the Big Darby could be improved particularly if the Flat Branch is the focus of the flood pulse capture;

2) an array of biologically diverse forested and wetland habitats would develop in land already purchased by The Nature Conservancy. Terrestrial and wetland fauna and flora would flourish in such an environment; and

3) wetlands at this location could also be designed to treat the minor flow coming from the Logan County wastewater treatment plant located adjacent to this proposed wetland restoration site.

The wetland/riparian area, which could be called something like the Upper Big Darby Creek Wetland Demonstration Park, could also become an ecotourism destination with signs from adjacent and heavily used US Route 33 and could be a good example of public and private partnership to improve the Darby Creek watershed. It could be modeled after the successful 12-ha Olentangy River Wetland Research Park at The Ohio State University (Mitsch and others 1998, Mitsch and Jørgensen 2004) and could also be eligible for Federal and state support as well as private development. Additional stream and riparian restoration approaches should also be investigated in this basin, but the initial focus is should be on restoring the Flat Branch.

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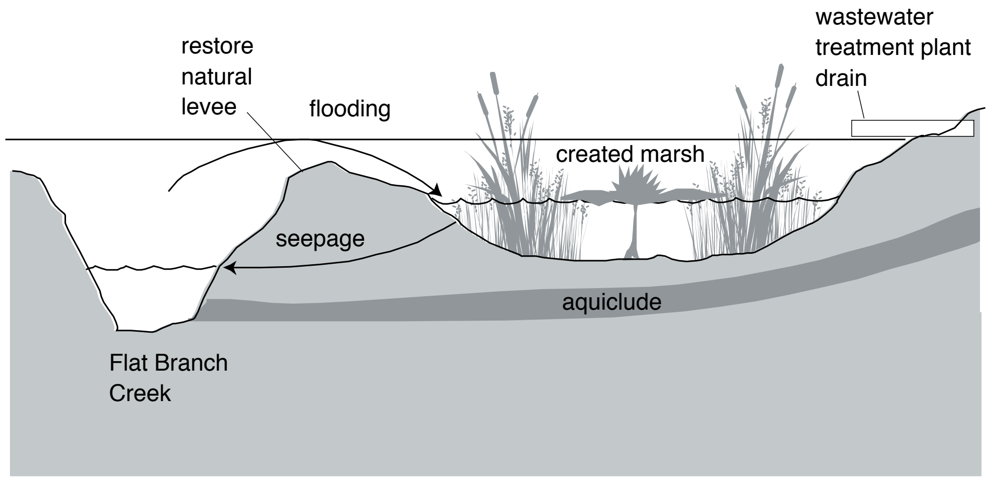

Figure 6. Conceptual diagram of riparian wetland creation/restoration at confluence of Flat Branch Creek and Big Darby Creek.

References

Allan JD. 1995. Stream Ecology: Structure and Function of Running Waters. New York: Chapman and Hall.

APHA. 1996. Standard Methods for Examination of Water and Wastewater. Washington, DC: American Public Health Association.

Costanza R, dArge R, deGroot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, ONeill RV, Paruelo J, Raskin RG, Sutton P , vandenBelt M. 1997. Value of the world's ecosystem services and natural capital. Nature 387: 253-260.

Cronan C, Schofield CL. 1979. Aluminum leaching response to acid precipitation: Effects on high-elevation watersheds in the northeast. Science 204: 304-305.

Dosskey MG, Bertsch PM. 1994. Forest sources and pathways of organic-matter transport to a Blackwater stream – A hydrologic approach. Biogeochemistry 24: 1-19.

ESRI. 2000. ArcView 3.0 version, ESRI Inc. Redlands, CA.

Goodwin CN, Hawkins CP, Kershner JL. 1997. Riparian restoration in the western United States: Overview and perspective. Restoration Ecology 5: 4-14.

Henry, CP., C. Amoros C., N. Roset N. 2002. Restoration ecology of riverine wetlands: A 5-year post-operation survey on the Rhone River, France. Ecological Engineering 18: 543-554.

Hoagalnd CR, Gentry LE, David MB and Kovaci DA. 2001. Plant nutrient uptake and biomass accumulation in a constructed wetland. Journal of Freshwater Ecology 16: 527-540.

Jacks G, Joelesson A, Fleischer S. 1994. Nitrogen retention in forested wetlands. Ambio 23: 358-362.

Kadlec RH, Hey DL. 1994. Constructed wetlands for river water quality improvement. Water Science and Technology 29: 159-168.

Lowrance R, Todd R, Fail J, Hendrickson O, Leonard R, Asmussen L. 1984. Riparian forests as nutrient filters in agricultural watersheds. BioScience 34: 374-377.

Mitsch, WJ., Wu, X, Nairn, RW, Weihe, PE, Wang, N, Deal, R, Boucher, CE. 1998. Creating and restoring wetlands: A whole-ecosystem experiment in self-design. BioScience 48: 1019-1030.

Mitsch WJ, Gosselink JG. 2000. Wetlands. 3rd ed. New York: J Wiley. 920 p.

Mitsch WJ, Day Jr. JW, Gilliam JW, Groffman PM, Hey DL, Randall GW, Wang N. 2001. Reducing nitrogen loading to the Gulf of Mexico from the Mississippi River Basin: Strategies to counter a persistent large-scale ecological problem. BioScience 51: 373-388.

Mitsch W.J., Lefeuvre JC, Bouchard V. 2002. Ecological engineering applied to river and wetland restoration. Ecological Engineering 18: 529-541.

Mitsch WJ, Jørgensen SE. 2004. Ecological Engineering and Ecosystem Restoration. New York: J Wiley. 411p.

Moustafa MZ. 1999. Nutrient retention dynamics of the Everglades nutrient removal project. Wetlands 19: 689-704.

Nairn RW, Mitsch WJ. 2000. Phosphorus removal in created ponds receiving river overflow. Ecological Engineering 14: 107-126.

Naiman RJ, Decamps H. 1997. The ecology of interfaces: Riparian zones. Annual Review of Ecology and Systematics 28: 621-658.

Odum EP. 1981. Foreword. In: Clark JR and Benforado J, (eds.). Wetlands of Bottomland Hardwood Forests. Amsterdam: Elsevier. pp. xi-xiii.

Ohio Environmental Protection Agency. 1989. Biological Criteria for the Protection of Aquatic Life Vol I-III, Surface Water Section, Division of Water Quality Monitoring and Assessment, Ohio Environmental Protection Agency, Columbus, OH.

Ohio Historical Society. 2001. Ohio History 1880 and 1885. Columbus, OH.

Peterjohn WT, Correll DL. 1984. Nutrient dynamics in an agricultural watershed – observations on the role of riparian forest. Ecology 65: 1466-1475.

Poff NL. 1997. The natural flow regime: A paradigm for river conservation and restoration. BioScience 769-784

Poudevigne I, Alard D, Leuven RS, Nienhuis PH. 2002. A system approach to river restoration: A case study in the lower Seine Valley, France. River Research and Applications 18: 239-247.

Richardson CJ, Vaithiyanathan P. 1995. Phosphorus sorption characteristics of Everglades soils along a eutrophication gradient. Soil Science Society of America J. 59: 1782-1788.

Richter BD. 1998. A spatial assessment of hydrologic alteration within a river network. Regulated Rivers: Research and Management 11: 329-340.

Spieles DJ, Mitsch WJ. 2000. The effects of season and hydrologic and chemical loading on nitrate retention in constructed wetlands: A comparison of low and high nutrient riverine systems. Ecological Engineering 14: 77-91.

Sweeney BW, Czapka SJ, Yerkes T. 2002. Riparian forest restoration: Increasing success by reducing plant competition and herbivory. Restoration Ecology 10: 392-400.

Tein A, Heiler G, Pennetzdorfer D, Riedler P, Schagerl M, Schiemer F. 1999. The Dunube restoration project: Functional aspects and planktonic productivity in the floodplain system. Regulated Rivers: Research and Management 12: 259-270.

The Nature Conservancy Ohio. 1999. Monitoring plan for the adaptive management of the Big Darby Creek watershed in Ohio. Dublin, OH: The Nature Conservancy. 132 p.

U.S. Environmental Protection Agency. 1980. EPA-Water Quality Criteria Documents: Availability. Federal Register 45 (231): 79318-79379.

U.S. Environmental Protection Agency. 1981. EPA-Water Quality Criteria: Corrections. Federal Register 46 (156): 40919.

U.S. Environmental Protection Agency. 1983. Methods for Chemical Analysis of Water and Wastes. 600/4-79-020, U.S. Environmental Protection Agency, Cincinnati, OH.

U.S. Environmental Protection Agency. 1996. Big Darby Creek Watershed Ecological Risk Assessment Case Study, Statement. Washington, DC.

Ward JV. 1998. Riverine landscapes: Biodiversity patterns, disturbance regimes, and aquatic conservation. Biological Conservation 83:269-278.

Ward JV, Stanford JA. 1995. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. Regulated Rivers: Research and Management 11: 105-119.

Ward JV, Tockner K, Schiemer F. 1999. Biodiversity of floodplain ecosystem and connectivity. Regulated Rivers: Research and Management 15: 125-139.

Whigham DF, Pittek MA, Hofmockel KH, Jordan TE, Peppin AL. 2002. Biomass and nutrient dynamics in restored wetlands on the outer coastal plain of Maryland, USA. Wetlands 22: 562–574.

Whitton BA. 1975. River Ecology. Los Angeles: University of California Press. 725p.

Yu Z, Schwartz FW. 1999. Automated calibration applied to watershed-scale flow simulation. Hydrological Processes 13: 191-209.